

DESCRIPTION**ELECTRONIC DEVICES COMPRISING THIN FILM TRANSISTORS**

5 The present invention relates to the manufacture of electronic devices comprising thin film transistors (TFTs) on an insulating surface, for example, a glass or insulating polymer substrate. The device may be, for example, an active matrix liquid crystal display (AMLCD) or other flat panel display.

10 For many years there has been considerable interest in developing thin-film circuits with TFTs on glass and/or on other inexpensive insulating substrates, for large area electronics applications. Such TFTs fabricated with amorphous or polycrystalline semiconductor films may form the switching elements of a cell matrix, for example, on the active plate of a flat panel display as described in United States Patent US-A-5,130,829 (Our Ref: PHB 33646).

15 Typically, the TFTs used in the active plate of a display have a lateral configuration, in that the source and drain electrodes are spaced laterally relative to the underlying substrate. The distance between these electrodes, which defines the channel length of the TFT, is determined using lithographic techniques. A uniform layer of electrode material is deposited, then patterned
20 using photolithography and etching. Such processes are expensive as the associated equipment is costly and has a low throughput, and use large quantities of photoresist and developer. They are also difficult to control accurately across a relatively large substrate, for example, when fabricating LCDs for television applications. In addition, lithographic equipment currently
25 available for use in manufacture is only able to reliably provide a minimum channel length of around 5microns over a relatively large substrate. Shorter channel lengths are desirable as they result in higher speed TFTs.

30 In a vertical TFT, the source and drain electrodes are spaced normally relative to the substrate and the size of this spacing is defined by the thickness of one or more layers of the TFT, rather than by using photolithography.

 A vertical TFT configuration is described in "Excimer-Laser-Produced Amorphous Silicon Vertical Thin Film Transistors" by Akihiko Saitoh and

Masakiyo Matsumura, Jpn. J. Appl. Phys. Vol. 36 (1997) pp668-9. The process used to fabricate the TFT disclosed in this paper defines source and drain regions without employing photolithography, by laser crystallisation of amorphous silicon. However, photolithography is subsequently used to define
5 the source and drain electrodes.

It is an object of the invention to provide an improved method of manufacturing an electronic device including a vertical thin film transistor.

The present invention provides a method of manufacturing an electronic device including a thin film transistor, comprising the steps of:

- 10 (a) forming a gate electrode on an insulating surface;
- (b) depositing an insulating layer over the gate electrode and a region adjacent an edge of the gate electrode, such that the insulating layer comprises two outer surfaces which are substantially parallel to, and mutually spaced normally of, the insulating surface with a step extending therebetween;
- 15 (c) depositing a layer of semiconductor material;
- (d) depositing a layer of electrode material;
- (e) depositing a layer of negative resist material over the electrode material layer, the resist material being soluble in a predetermined solvent;
- (f) irradiating the resist layer to render exposed portions insoluble in the
20 predetermined solvent, the portion overlying the step being insufficiently exposed such that it remains soluble;
- (g) developing the resist layer using the predetermined solvent, thereby removing the portion overlying the step; and
- (h) removing the portion of the electrode material layer exposed by step
25 (g) to define source and drain electrodes which extend over a respective one of the outer surfaces of the insulating layer to the step.

It may often be preferable to deposit the semiconductor layer before the electrode layer is deposited and patterned. For example, when using amorphous silicon, it is generally preferable to deposit it directly onto the
30 insulating layer to provide a sound interface therebetween. However, in another preferred embodiment, step (c) of depositing the semiconductor layer is carried out after step (h). This is beneficial when using a semiconductor

material which is not sufficiently resistant to the process used in step (h) to remove part of the electrode material layer. For example, polymeric semiconductors are not generally resistant to etchants likely to be used in patterning the electrode layer.

5 Preferably, the edge of the gate electrode is substantially normal to the insulating surface, resulting in a substantially vertical transistor channel. Nevertheless, it may be desirable to form the gate electrode edge at an angle to the substrate, forming a similarly angled transistor channel. It will be appreciated that in fabricating such a device according to the method of the invention, it will be necessary to adjust the angle of incidence of the radiation employed in step (e) so that the it is substantially aligned with the gate electrode edge.

10

A second thin film transistor may be formed simultaneously with the first thin film transistor at the edge of the gate electrode opposing the transistor channel of the first.

15

A low definition process may be used to define one or more, or all of the gate electrode and the other layers. As will be appreciated by the skilled person, photolithography is an example of a high definition process, whilst a low definition process may be a printing process such as gravure-offset printing, inkjet printing, or micro-dispensing. Photolithography requires the use of expensive vacuum equipment which has a relatively slow throughput. Low definition processes may often be achieved without the need for vacuum equipment. According to the method of the invention, the critical patterning step, that is the definition of the source and drain electrode spacing and therefore the TFT channel length, is achieved without the use of photolithography, and the use of vacuum equipment may be avoided. As the definition of the other TFT layers is generally less critical, it may be achieved with sufficient accuracy using relatively low cost, low definition processes. This particularly applies to AMLCDs with larger pixel sizes, such as a liquid crystal TV which may have a screen diagonal of greater than 20" (510mm). In a 25" (635mm) screen, a VGA display has a pixel size of 265 x 795 microns. In large pixels, the required channel aspect ratio, expressed as width divided

20

25

30

by length, is large as well. Thus, the width of the channel may be defined by a relatively coarse definition process such as printing.

With printing techniques, materials are directly deposited in the required pattern, which avoids material wastage and may reduce the number of processing steps required. For example, resist materials may be printed onto layers of material deposited conventionally as a continuous blanket. Also, precursor materials may be printed onto a substrate and then converted into materials with the desired electrical properties by further processing steps.

The semiconductor material may comprise an organic, or more particularly, a polymeric material. These materials may be particularly suited to use in low definition processes such as printing or other low cost large area production techniques which may not require the use of expensive vacuum equipment, as they can be deposited in solution by techniques such as spin coating.

Preferably, the height of the upper surface of the gate electrode above the substrate is in the range of 0.05 to 1.5 microns. This in turn dictates the length of the transistor channel in the finished device.

Prior to the step of removing the portion of the electrode material layer exposed by the patterned resist layer, it may be advantageous to subject the resist layer to a reflow process and/or an ashing process, to improve the definition of the pattern in the resist layer.

An embodiment of the invention will now be described by way of example and with reference to the accompanying schematic drawings, wherein:

Figures 1 to 4 are cross-sectional views of a TFT of an electronic device at stages in its manufacture by a method in accordance with a first embodiment of the present invention; and

Figure 5 shows a cross-sectional view of a TFT of an electronic device fabricated in accordance with a second embodiment of the invention.

It should be noted that the Figures are diagrammatic and not drawn to scale. Relative dimensions and proportions of parts of these Figures have been shown exaggerated or reduced in size, for the sake of clarity and convenience in the drawings.

5 Figure 1 shows the first stage in the fabrication of a TFT according to a method embodying the invention. Firstly, the gate electrode 2 is provided on an insulating substrate 4. In an AMLCD for example, the insulating substrate may typically be formed of glass or a polymeric material, and the gate electrode of chromium. The gate electrode may be formed in a known manner by deposition of a layer of metal by sputtering, followed by a photolithographic patterning process. Alternatively, a printing process may be used.
10

The thickness of the gate electrode (that is, the height of its upper surface above the substrate) dictates the length of the transistor channel in the finished device. Typically, it may be around 1 micron, and may be varied from
15 0.05 up to 1.5 microns, for example. This lower value is dictated by current processing equipment, as it becomes difficult to reliably control the layer thickness below values of this order. At gate thickness around or above 1.5 microns, the time taken to sputter deposit the layer becomes increasingly significant and also as the channel length increases, the TFT switching speed
20 reduces.

An insulating layer 6 is then deposited over the gate electrode 2 and also extends over a region of the substrate adjacent to the gate electrode. The insulating layer 6 may be a single layer of, for example, silicon nitride or it may comprise a number of layers of insulating material. It may be deposited
25 by a known plasma enhanced chemical vapour deposition (PECVD) process to a thickness of around 300nm.

A layer of semiconductor material 8, for example hydrogenated amorphous silicon, is formed over the insulating layer 6. An amorphous silicon layer may be provided using a known PECVD process, and may have a thickness of around 160nm. A contact layer 10 is provided over the semiconductor layer 8, which may typically be formed of n+ doped silicon, deposited by a known PECVD process to a thickness of around 40nm.
30

Next, a layer of electrode material 12 is defined over the contact layer 10. A suitable electrode material is a metal such as chromium for example. As with the gate electrode, this may be formed using a sputtering process. This is followed by a layer of negative resist 14. Each of the layers deposited 5 over the gate electrode has a step therein corresponding to the edge 16A of the gate electrode.

As illustrated in Figure 2, the negative resist 14 overlying the structure shown in Figure 1 is then exposed to radiation 18 modifying the composition of the irradiated areas thereof. For example, using a resist consisting of Nano 10 XP SU-8 2 made by MicroChem Corporation, this is achieved using ultraviolet light. The radiation is incident at an angle substantially normal to the substrate, such that a portion 20 (shaded in Figure 2) of the resist overlying the step is substantially shadowed and not fully exposed owing to the relatively large normal thickness of the resist at the step in the layer.

15 As a negative resist is used, the irradiated regions are rendered insoluble in a specific solvent, such as Microposit EC Solvent if Nano XP SU-8 2 resist is used, whilst the shadowed region remains soluble. The resist pattern can therefore be developed by immersing the structure in the solvent, removing portion 20 and retaining the remainder of the resist layer. The resist 20 pattern may be improved by subjecting it to a reflow process after the development step. For example, with of Nano XP SU-8 2 resist, this may be achieved by heating at 150°C for about 30 minutes. The reflow process reduces the amount of residual resist on the vertical step surface, and also on the horizontal surfaces adjacent the step. This results in a resist pattern as 25 shown in Figure 3 which extends over the upper and lower outer surfaces 22 and 24 of the electrode layer 12 up to the step. It may be desirable to improve the resist pattern further by ashing to remove excess resist overlying areas to be etched.

Using the remainder of the resist layer as a mask, the exposed portion 30 of the electrode layer 12 and the underlying portion of the contact layer 10 are then removed, for example by an etching process. The resist material is then removed, to leave the finished TFT structure shown in Figure 4. The

remaining resist may be removed using a known stripper such as fuming nitric acid. Portions 26 and 28 of the electrode layer and the underlying contact layer extend over the semiconductor layer to the step, forming source and drain regions (respectively or vice versa). The length 30 of the transistor channel 32 in the underlying semiconductor layer 8 is defined therebetween.

As an alternative to the process flow illustrated in Figures 1 to 4, the semiconductor layer 8 may be deposited after the electrodes 26 and 28 have been patterned, resulting in the TFT structure shown in Figure 5. This may be a suitable approach when using a polymeric semiconductor material which is not sufficiently resistant to the etchant needed to pattern the electrode layer. In this embodiment, the contact layer 10 can be omitted. It may be less desirable when using amorphous silicon as the semiconductor material, as it may compromise the quality of the interface between the amorphous silicon and the insulating layer.

The configuration shown in Figures 4 and 5 is advantageous in that it has a relatively low electrode to gate capacitance for the portion 28 which overlies the substrate rather than any part of the gate electrode 2. In an AMLCD, it may therefore be preferable to connect this region to the pixel electrode, rather than region 26, as the kickback voltage of the respective pixel is dependent on the magnitude of the capacitance between the drain electrode of the TFT and the gate electrode.

In Figures 1 to 5, the TFT formation process has been shown as creating a TFT structure alongside one edge 16A of the gate electrode for clarity. However, a corresponding structure would in practice be simultaneously formed alongside the opposing edge 16B which may be desirable in some applications. It may be preferable to inhibit the formation of such a corresponding structure, for example when fabricating an AMLCD. This may be achieved for example by altering the angle of incidence of the radiation to which the negative resist is exposed such that only one edge is shadowed.

In the process described in relation to Figures 1 to 4, a single resist layer mask is used in the procedure of etching away both electrode layer 12

and contact layer 10 material. Alternatively, one mask may be formed in the manner described above over the contact layer 10 to mask etching of the contact layer material, and then the mask removed, an electrode layer deposited and a second mask formed in the same manner prior to etching of the electrode layer. This approach involves more process steps than the use of a single mask, but may be appropriate where different etchants are used in each etching process to provide a greater selectivity of the etchant between the layer to be etched and the underlying layer.

It will be appreciated that other semiconductor materials than amorphous silicon may be used to form the body of the transistor. For example, nanocrystalline silicon, polysilicon, II-VI semiconductors such as CdTe, III-V semiconductors such as GaAs could be employed. Also, organic semiconductors (such as pentacene) and more particularly polymeric semiconductors (such as poly 2,5-thienylene vinylene) may be preferred, and may allow flexible devices to be formed on a flexible substrate. Furthermore, organic-inorganic hybrid semiconductor materials may be used.

The TFT configurations described above are not only applicable to the field of AMLCDs, but also other applications, particularly where arrays of thin film devices are required such as in other large area electronic devices. Examples of these devices are active matrix polymer LED displays, or large area detectors, such as X-ray detectors for medical use or fingerprint sensors.

From reading the present disclosure, other variations and modifications will be apparent to persons skilled in the art. Such variations and modifications may involve equivalent and other features which are already known in the design, manufacture and use of electronic devices comprising thin-film circuits, semiconductor devices, and component parts thereof, and which may be used instead of or in addition to features already described herein.

Although Claims have been formulated in this Application to particular combinations of features, it should be understood that the scope of the disclosure of the present invention also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof; whether or not it relates to the same invention as

presently claimed in any Claim and whether or not it mitigates any or all of the same technical problems as does the present invention. Features which are described in the context of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features which are, for 5 brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination. The Applicants hereby give notice that new Claims may be formulated to such features and/or combinations of such features during the prosecution of the present Application or of any further Application derived therefrom.